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ON THE HEIGHT OF THE 5577 Å [OI] AIRGLOW LAYER IN HAWAII

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Abstract

In using the Van Rhijn Method for determining heights of the airglow-emitting layers one must take into account and satisfy the assumptions involved. It is even more important to eliminate completely the contribution that is due to the extraterrestrial radiations and to the airglow continuum contaminating the spectral line intensity measurements and to know the value of the extinction coefficient at the observing station. After due consideration was given these two factors, we found that the height of the 5577 Å [OI] airglow layer at Mt. Haleakala (Hawaii, U.S.A.) was 145 ± 14 km.

This may be interpreted as (1) the real height in the tropics due to a single emitting layer or (2) an effective height due to two layers, the stronger component being at 100 km and the weaker one in the vicinity of the F region of the ionosphere. Evidence favors the latter conclusion.

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ON THE HEIGHT OF THE 5577 Å [OI] AIRGLOW LAYER IN HAWAII

1. Introduction

Heights of the emitting layers of the Night Airglow are found by (1) ground-based observations and (2) rocket observations. The ground-based observations can be further categorized as involving two (or more) stations determining height by triangulation [1], and a single station [2]. Observations from a single station can be utilized to compute the height of the emitting layer by the Van Rhijn Method [3], of course taking into account the lower atmosphere.

Sample calculations from Haleakala* of the height of the 5577 Å emission layer indicated that it was around 150 km while at mid-latitudes its height is estimated to be around 100 km. Mid-latitude emission heights found by rocket experiments are also around 100 km. With this in mind and also the fact that (a) the extinction coefficient at Haleakala has been carefully measured and found to be quite stable and (b) the Haleakala airglow photometer does not respond to the extra-terrestrial and airglow continuum components, it appeared worthwhile to undertake a thorough analysis of the Haleakala data for 15 nights in September and October 1962.

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* Geographic Latitude 20° 43'N, Longitude 156° 16' W
Geomagnetic Latitude 20° 50' N, Longitude 88° 27' W
Height above sea level 10,012 feet (3,052 meters)

2. The Site and the Observations

The determination of the radiative transfer through the atmosphere is an essential but difficult part of the problem of deducing height of the airglow layer, especially when unknown and varying amounts of dust and man-made contaminants are present in the lower atmosphere. Guiding numbers which contribute individually to the extinction coefficient have been given by Allen [4]. Determination of the extinction coefficient (τ) at a place is a separate task and usually, when height determinations are made, this coefficient is assumed as a best guess from the experience of the experimenter and from the guiding numbers obtained experimentally at some other station. Unless this judgment is very sound,the reliability of the height results becomes very quiestionable. This problem is somewhat simplified at a station like Mt. Haleakala, which is at an elevation of 3052 m on the small mid-Pacific island of Maui. There is no large urban or industrial complex on the island and as the observatory is sited above the trade wind inversion it is free from the effects of city glare and low-level dust and smoke.

Besides extinction, scattering of light also has to be taken into account. Intensities of scattered light for known or assumed scattering coefficient, albedo, and various zenith distances have been tabulated by Ashburn [5] from Chandrasekhar's equations. Ashburn's tables are restricted to the Rayleigh scattering.

It has been shown [6] that the photometric quality of the sky at Mt. Haleakala is excellent. At this station the content of water vapor is also negligible.

The observations used for this analysis were obtained from a birefringent photometer [7, 8] which has been in operation at Mt. Haleakala since 1961. This photometer uses an auxiliary interference filter with 13 Å half-width and 54°/o transmission at 5577 Å with a maximum transmission of 67°/o at 5574 Å. The half-width of the filter system is 6 Å. With the rotating polaroid behind the birefringent element, the filter scans the airglow spectrum 100 times per second, alternately including and excluding the 5577 Å line on the continuous spectral background in 6 Å region around 5577 Å, thus giving a modulated A.C. signal for the line emission only, eliminating the continuum as the unmodulated D.C. signal. The basic principle and helpful suggestions for the construction of the birefringent filter have been given by Evans [9]. The optics, filter system, and the RCA 7265 photomultiplier are mounted on an alt-azimuth mounting, scanning the sky in almucantars of 80°, 75°, 70°, 60°, and 40° zenith distances, plus a scan at the zenith. Scanning speed is 10°/sec, so that a complete survey requires about five minutes. A survey for 5577 Å radiation is repeated every 15 minutes. The signal from the photomultiplier after synchronous detection and amplification is recorded on chart paper. Readings 22-1/2° apart on the azimuth for a fixed altitude are read from this chart and punched on IBM cards, giving 16 readings in azimuth for one zenith distance plus one reading for the zenith; thus, an entire survey of sky consists of 81 readings which is accommodated on five IBM cards. These data are further processed by a computer.

The quality of the observing site ensures constancy of the extinction coefficient while use of the birefringent filter photometer completely eliminates the continuum near the spectral emission line. These points are stressed here because it will be shown later how seriously they affect the results.

3. The Van Rhijn Method

The zenith angle dependency of the intensity due to a thin homogeneous emitting layer, concentric with the earth, was formulated by Van Rhijn by the relation

$$V_z^* = \frac{I_z}{I_o} = \frac{1}{\sqrt{1 - \frac{R^2}{(R+h)^2}\,\mathrm{Sin}^2 z}} \quad , \qquad (1)$$

where I_z and I_o are the intensities at zenith angles z° and 0° , and R and h are the radius of the earth and the vertical height of the emitting layer respectively from the ground. So that

$$h = R \left\{ \frac{V_z \mathrm{Sinz}}{\sqrt{V_z^{\,2} - 1}} - 1 \right\} \quad . \qquad (2)$$

The effect of the lower atmosphere is not taken into account.

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* The ratio of the intensity observed at a given zenith distance to that at the zenith is denoted by V_z'; when the observations are corrected for the atmosphere V_z is the ratio "outside the atmosphere". The Van Rhijn formula uses V_z values.

One can understand why many people are skeptical about this method, primarily because the results obtained with it vary widely. This wide variation may be atrributed to the following:

(1) Experimental technique used to obtain the data and the analysis of the data are inadequate; specifically (a) the spectral line emission is not completely isolated from the observed intensity measurement because of improper subtraction of the "background", (b) assumed scattering and extinction coefficients in analysis may be incorrect.

(2) The assumption regarding the uniformity and symmetry of the layer is not closely approximated.

(3) It is just possible that the layer may not be thin with a more or less sharply defined maximum in intensity with respect to height. It may be a thick and diffused layer. Moreover, wide variations in height with time are not unexpected. It may not be out of place here to quote S. Chapman [15] "There is no doubt that the upper atmosphere changes more irregularly than we are accustomed to think it does... I have no doubt that it is decidedly streaky and irregular, and that there are irregular motions as well."

The Van Rhijn Method could be used to its greatest advantage by improving the experimental technique and the method of analysis, and by the proper selection of data. Even if this is not the best method (no existing method can really be claimed as the best; each method has its own disadvantages) it is certainly a useful method within its own limitations.

In the present paper we have corrected the observations to outside the atmosphere, in order to account for the lower atmosphere, by the method outlined by Roach, Megill, Rees, and Marovich [14].

The basic idea is to obtain the V_Z value which can be directly used in equation 2 to calculate the height, from the V'_Z value obtained experimentally, by using the relation

$$V_Z = \frac{(V'_Z - S'_Z)\ \exp(\tau m_Z)}{(1\cdot 000 - S'_0)\ \exp(\tau m_0)} \tag{3}$$

where m_0 and m_Z are the air masses (referred to unity in the zenith at sea level) at the observing station at the zenith and at zenith distance z, and S'_0 and S'_Z are the values of the scattered light expressed as a fraction of the observed total brightness of the zenith for the said zenith distances. The value of τ is taken as ~~0·31~~ 0·131.

4. The Extinction Coefficient

In 1961-62 regular measurements of the extinction coefficient were done in 5300 Å by Dr. Weinberg for his zodiacal light studies. His measurements show that the extinction coefficient remained very steady from night to night and even from month to month (until the Bali volcanic eruption in March 1963). Before this date the values of the total extinction coefficient referred to sea level in 5300 Å varied between 0.138 to 0.145 [16]. Before the uniqueness of the site can be claimed, it is felt that more systematic observations of the extinction coefficient are needed. However, these observations indicate that possibly Haleakala is one of the best sites in the world.

For the present study, the measured value of 5300 Å extinction coefficient was corrected to 5577 Å. This correction was based on the Mt. Wilson curve of extinction coefficient against wave length. As there is very little variation of τ_{5300} from night to night, it is reasonable to assume that τ_{5577} would remain constant and its value found as described above was taken to be 0.131 (referred to sea level). The molecular scattering coefficient is taken as 0.09 for 5577 Å [4].

5. Selection of Data

It was felt important to select nights which had data that would be useful for reduction by the use of the Van Rhijn formula. This selection follows the assumptions in the theory. For this reason "quiet" nights were selected on which activity was at a minimum. However, from an examination of the data it was found that nights that are absolutely quiet are exceptional in the tropics. On many nights the intensity patterns change very rapidly in time and space, especially in 6300 Å radiation and to a lesser extent in 5577 Å radiation. However, it is possible to select nights that are fairly quiet. The preliminary examination of quiet and active nights was made by analysis of the correlation coefficient of the 5577 Å and 6300 Å radiations. Data of zenith intensities only obtained from another fixed photometer, which is in operation near the birefringent photometer, were used for this analysis to give the indication, though, often a night may be quiet at the zenith but active at greater zenith distances. Usually on quiet nights the correlation coefficient of 5577:6300 is insignificant (0.2 or so), while on active nights it is considerably higher (0.5, or higher) [10]. In the mid-latitudes Barbier [11] has found the correlation between the two radiations to be insignificant. Results obtained in Japan [12] are also similar.

The assumptions in the Van Rhijn Method, at the outset, point out that the method works for a uniformly bright night, that is, a quiet night without much patchy structure. Very bright local patches at great zenith distances tend to increase the Van Rhijn ratio, giving a lower over-all height (which is, of course, a false height). Simultaneous studies of ionograms with 6300 Å intensity have shown here [13] that the height of the emission layer on many occasions lowers with the increase in the brightness. If this were also true for the 5577 Å emission, then the bright local patches would tend to decrease the over-all height. Small differences in brightness on large parts of the sky could be averaged out by taking a very large number of observations for the same zenith distance. Thus, it is felt that the Van Rhijn Method should work better with (1) quiet nights having (2) a large number of observations.

6. Results

Table 1 gives the log of the data used for the height determination. Tables 2a and 2b show the results obtained with the analysis of 15 nights in September and October 1962. Table 2a was prepared by taking the complete data of all nights, while Table 2b shows the results after the data were "edited". All these nights were such that the correlation coefficient for each whole night for 5577 Å to 6300 Å was very insignificant. The heights, with their probable errors, obtained by using data from 80°, 75°, and 70° zenith distances are presented.

We have purposely selected the data from the zenith distances 80°, 75°, and 70° for finding the height, while those from the zenith distances 40° and 60° were rejected for the reason that the calculated height becomes very sensitive to small changes in V_Z at small zenith distances. The height of the layer changes by 15 km when V_Z (40°) changes by 2 in the third decimal place. It is not possible to claim this accuracy in measurements with the present setup.

Among the chosen three zenith distances it will be seen from Table 2a or 2b that the probable error in height determination for zenith distance 75° is the smallest, while for 70° and 80° it is larger. It may be noted that signals (deflections on the recording chart) for large zenith distances are greater than those for the small zenith distances, resulting in larger percentage error for the small rather than for the large zenith distances when scaling the charts. Table 3 shows the accuracy required in the I_Z/I_O value for claiming 15 km accuracy in the results. Larger probable error in height from the 70° zenith distance data compared to that from the 75° zenith distance data may be attributed to the above cause. The height found from 80° zenith distance data suffers from the following. At 80°, (1) intensity of scattered light changes very rapidly with the zenith distance, and as the photometer has a finite field of view, a scattering value assumed for 80° scattering may be different from the actual value which is entering through the finite field. (2) the mechanical mounting has to have greater accuracy in this region because with a small change in zenith distance, the heights would change considerably due to large changes in the thickness of the layer involved. The results therefore indicate that 75° zenith distance is the best compromise for height analysis and may be considered as optimum.

In editing the data it is assumed that the height is not less than 0 km and not greater than 300 km ($0 < h < 300$). Sets of observations where ridiculous heights, viz., negative heights or heights greater than 300 km are obtained, were rejected. Such absurd heights could only be obtained when the intensity at larger zenith distances is abnormally high; the V_Z^0 values are than very high, giving negative heights. On the other hand if the zenith is locally bright, V_Z^0 is unusually small giving very large heights. In both cases the height results are inaccurate. Even with the present selected nights, about 14°/o of the observations had to be rejected for the above reason.

The edited data in Table 2b show that the probable error in height determination is definitely low for all the three zenith distances and more so for 75° zenith distance where the value of the probable error is better by 60°/o compared to that from the unedited data (Table 2a). The value of the height itself is only very slightly lower (about 2.6°/o) when compared to the value from the unedited data. It is rather surprising that the refinement is quite insignificant, considering the nature of the phenomenon. This therefore points out that the essential factor for working with this method is the availability of a very large amount of data, while editing assumes secondary importance. Of course, a large amount of edited data may present more reliable results. In the present investigation about 9800 and 8500 individual observations are utilized for each zenith distance with unedited and edited data respectively, so that the final weighted height involves about 30,000 and 25,000 individual observations respectively. One V_z' value is found from the average of 16 azimuthal intensity values divided by the zenith intensity. In other words the final weighted height results from 1500 height values. It may be noted that the values of probable errors as presented in Tables 2a and 2b are obtained by taking into account the single height value, for each night under study, as the true height. As a matter of fact this single height value has a probable error which is disregarded in Tables 2a and 2b. If, therefore, each individual height determination of the 1500 total determinations is given equal weight and the data treated as one sample, a height of 144 km with a probable error of ± 60 km is obtained.

In order to see whether the height of the emitting layer changes systematically during the early and late parts of the night, observations of each night were divided into two nearly equal groups and the heights for premidnight and postmidnight periods were calculated for all 15 nights. The weighted mean pre- and postmidnight heights show no significant difference. Weights given were inversely proportional to the probable errors.

7/ Discussion

The computed weighted height of the 5577 Å layer points to two possibilities.

(1) A single layer exists at about 150 km.

(2) There are two layers--one possibly at 100 km and another much higher, giving the optical "center of gravity" at the observed value of about 150 km.

Case (1) may result from a thin layer which is consistent with the Van Rhijn assumption or from a thick layer for which the Van Rhijn euqation has to be modified. If the rate of emission is assumed to be constant over the height interval $h_2 - h_1$, where h_1 and h_2 are the lower and upper boundaries of the emitting layer from the ground, the intensity ratio V_z will be given by [18]

$$V_z = \frac{R + h_2}{(h_2 - h_1)\ V_z(2)} - \frac{R + h_1}{(h_2 - h_1)\ V_z(1)} \qquad (4)$$

where $V_z(1)$ and $V_z(2)$ are the intensity ratios as would be obtained at heights h_1 and h_2 respectively. This resultant V_z value can be associated with an "effective emitting height" with the help of equation (2). Starting with a single layer at 150 km, if the layer is considered to be gradually thickening, Table 4 shows the effective emitting height H as obtained from equation 4 when the lower and upper boundaries of the layer assume the values shown in the table.

In the tropics, the height of 5577 Å[OI] emission layer in the vicinity of 190 km has been reported [17] at Poona (India).

However, it is not certain whether this height value is real or is due to an assumption of the extinction coefficient, since it was not measured for the place. Further, elimination of background radiation was done by two-filter method, which involves additional uncertainties.

Direct determination of the height of the emitting layer in the tropics by use of rockets has not been reported so far. However, there is reason to believe that the 5577 Å layer has two components in the tropics, as suggested for case 2, and, if so, it is more probable that there may exist a more or less permanent layer at about 100 km, intensity variation of which is independent of that of the 6300 Å radiation, as in the mid-latitudes, and which contributes a major share in the total intensity measurement of the 5577 Å radiation. Another 5577 Å radiation layer may be much higher, varying in intensity more or less in synchronization with that of the 6300 Å radiation, and contributing a smaller share to the total 5577 Å intensity as measured from the ground.

To fit their experimental results, two layers, one at 1000 km contributing 73°/o intensity and another at 50 km with 27°/o intensity, were proposed as early as 1944 by P. Abadi, A.Vassey, and E. Vassey [19]. They had assumed that the observed intensities were pure atmospheric emissions without any contamination from starlight and zodiacal light. Using the same data and assuming contributions of 60°/o and 40°/o intensity for the 5577 Å [OI] line and the integrated extraterrestrial light, respectively, it was shown by Roach and Meinel [20] that the same data are consistent with a single 5577 Å emitting layer at a height of 130 km. Besides the reinterpretation of the data, it may be pointed out that the filters used in the above investigation were very broad, (though they were "narrow" in those days!) and it is extremely difficult to eliminate the background correctly and completely, which is very necessary in the height analysis. Table 5 shows the influence of the background on the height determination. For the two intensity values of I_{75} and I_0 ("outside the atmosphere") (say through a filter) there is shown how the height value may change if the background is not eliminated from the line emission. Further, the necessity for a proper assumption of the value of the extinction coefficient has already been pointed out.

In the present investigation, we have reason to believe that there are two components to the layer. Again, this is inferred from the correlation coefficient analysis. During quiet nights, as already mentioned, the correlation coefficient of 5577 to 6300 is insignificant, but during active nights the same shows some positive correlation. The height of 6300 Å radiation is usally associated with the F region of the ionosphere, and excellent correlation has already been reported [21, 22] between the electron number density of the F region and the quantum emission rate of the 6300 Å line. Therefore, the nature of correlation during active and quiet nights may possibly be explained as follows:

1. During quiet nights the principal component of 5577 Å radiation comes from the layer at 100 km while a weak component may exist at a greater height (300 to 350 km).

The 6300 Å radiation is assumed to be radiated from a layer at about 300 to 350 km.

2. During active nights, because of the increase in the electron number density in the F region, the rate of reaction producing the 6300 Å emission may increase several tens of times when probably the component of the 5577 Å radiation, assumed to be produced in this region (associated with greater height) is also enhanced, thus giving over-all better correlation, in 5577 Å and 6300 Å, during the activity. This hypothesis is represented diagramatically in Figure 1. The intensities in this figure may be taken as a rough guide only to show the nature of the phenomenon.

Barbier has suggested [23] a formula for an extensive layer which could be represented by two thin layers characterized by intensities I(1) and I(2). If the Van Rhijn functions for the two layers are defined as

$$V_z(1) = \frac{I_z(1)}{I_o(1)} \quad \text{and} \quad V_z(2) = \frac{I_z(2)}{I_o(2)} \quad \text{for a zenith}$$

distance z then the Van Rhijn function* for the resultant layer due to the said layers is

$$V_z = \frac{I(1)\ V_z(1) + I(2)V_z(2)}{I(1) + I(2)} \tag{5}$$

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* All Van Rhijn functions in the present equation are those outside the atmosphere.

If it is assumed that the first layer is fixed at 100 km and the optical center of gravity of the resultant layer due to two thin layers is at 150 km (as has been found in the present investigation), then from Table 6 it will be seen that the second layer at 300 km will contribute about 33°/o of the total intensity.

Unfortunately, this proposed hypothesis of two layers cannot be tested by the Van Rhijn Method as this gives a single height value from intensity observations at two zenith distances. One may expect that during an active night when the higher component of the two layers is contributing to a somewhat greater extent the resultant effective height would be higher than that on a quiet night. However, according to our observations, during active nights the intensity patterns over the dome of the sky are invariably patchy and hence the Van Rhijn Method cannot be used.

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Table 1. Log of the Data Used for the Height Analysis

Night No	Date 1962	Hawaiian Standard Time Observations		Total Number of Surveys	Sky Conditions*
		From	To		
1	Sept 23/24	1945	0400	21	VG
2	28/29	2130	0530	33	G
3	29/30	1915	0530	42	E
4	Sept 30 Oct 1	1945	0530	42	E
5	Oct 1/2	1915	0530	41	VG
6	3/4	1915	0300	31	G
7	4/5	2130	0530	32	G
8	5/6	1915	0530	42	E
9	20/21	1845	0445	41	VG
10	25/26	1845	0530	41	E
11	26/27	1930	0545	40	E
12	27/28	1845	0530	44	E
13	28/29	1845	0530	44	E
14	29/30	1845	0530	44	E
15	30/31	1845	0545	37	E

* E = Excellent, VG = Very Good, G = Good, F = Fair, P = Poor

Table 2a. Height of 5577 Å Layer (Unedited Data)

Night No	Date 1962	$H_{80°}$*	$H_{75°}$*	$H_{70°}$*	Surveys
1	Sept 23/24	148 km	123 km	138 km	21
2	28/29	201	155	144	33
3	29/30	171	143	145	42
4	Sept 30 Oct 1	141	111	89	42
5	Oct 1/2	169	149	155	41
6	3/4	235	198	205	31
7	4/5	197	147	157	32
8	5/6	137	86	71	42
9	20/21	152	184	213	41
10	25/26	104	113	134	41
11	26/27	104	112	116	40
12	27/28	138	164	182	44
13	28/29	112	138	159	44
14	29/30	130	163	186	44
15	30/31	101	117	118	37
Mean Height		150 km	144 km	153 km	
Probable Error		± 26 km	± 17 km	± 22 km	

* $H_{80°}$, $H_{75°}$, $H_{70°}$ = Height calculated by using observations of 80°, 75°, and 70° zenith distances, respectively

Average Weighted Height (using all observations) 149 ± 22 km

Table 2b. Height of 5577 Å Layer (Edited Data)

Night No	Date 1962	$H_{80°}$*	No. of Surveys	$H_{75°}$*	No. of Surveys	$H_{70°}$*	No. of Surveys
1	Sept 23/24	155 km	18	135 km	18	148 km	18
2	28/29	204	29	161	29	155	29
3	29/30	172	30	146	30	157	30
4	Sept 30 Oct 1	168	34	149	34	143	34
5	Oct 1/2	151	37	134	38	143	33
6	3/4	183	19	164	20	173	20
7	4/5	199	25	154	25	183	23
8	5/6	156	34	114	34	128	31
9	20/21	136	37	159	37	167	34
10	25/26	107	39	123	40	128	38
11	26/27	108	39	118	39	134	37
12	27/28	135	39	152	40	166	38
13	28/29	112	44	138	44	141	39
14	29/30	127	43	146	39	152	35
15	30/31	101	34	117	34	109	24
Mean Height		148 km		140 km		148 km	
Probable Error		± 22 km		± 10 km		± 13 km	

* $H_{80°}$, $H_{75°}$, $H_{70°}$ = Height calculated by using observations of 80°, 75°, and 70° zenith distances, respectively

Average Weighted Height (using all observations) 145 ± 13 km

Table 3. Accuracy Required in V_z Values

for 15 km Change in the Height

Zenith Distance ($Z°$)	h, km	V_z	ΔV_z for Δh = 15 km	Change of V_z in 1000 for 15-km change in height
40	135	1.2869	0.0020	
40	150	1.2849	0.0012	1.5
40	165	1.2837		
60	135	1.8871	0.0110	
60	150	1.8761	0.0108	11
60	165	1.8653		
70	135	2.5553	0.0326	
70	150	2.5227	0.0305	31
70	165	2.4922		
75	135	3.0782	0.0551	
75	150	3.0231	0.0548	55
75	165	2.9683		
80	135	3.7800	0.1103	
80	150	3.6697	0.1007	105
80	165	3.5690		

Table 4. Height of the Resultant Effective Layer

Due to a Thick Uniform Layer

Lower Boundary, h_1 km	Upper Boundary, h_2 km	Thickness of the layer, $(h_1 - h_2)$ km	Effective height, km
140	160	20	149
130	170	40	149
120	180	60	149
110	190	80	148
100	200	100	148
90	210	120	147
80	220	140	146
70	230	160	145
60	240	180	144
50	250	200	142
0	300	300	141

Table 5. Influence of Background Radiation on Height Determination

% Background of I_0^*	$I_{75}^* - x$	$I_0^* - x$	I_{75}/I_0	Height,
x	I_{75}	I_0	V_z	km
0	50.00	25.00	2.0000	734
20	45.00	20.00	2.2500	499
25	43.75	18.25	2.3972	400
30	42.50	17.50	2.4285	382
35	41.25	16.25	2.5385	324
40	40.00	15.00	2.6667	267
45	38.75	13.75	2.8181	211
50	37.50	12.50	3.0000	151
55	36.25	11.25	3.2222	102
60	35.00	10.00	3.5000	50

I_{75}^* and I_0^* are intensities "outside atmosphere" for zenith distances 75° and 0°, respectively, including the background. I_{75} and I_0 are those when the background is subtracted. (50 and 25 units in the first row are intensity values from a two-color photometer)

Table 6. Height of the Second Layer, if the First Layer is Fixed at 100 km and the % Intensity Contribution Due to Both is Varied. The Resultant Height Due to Both Layers is Assumed to be 150 km.

% Intensity Contribution Due to Layer 1	% Intensity Contribution Due to Layer 2	Height of Layer 2, km
0	100	150
15	85	160
26	74	170
34	66	180
40	60	190
45	55	200
54	46	226
60	40	251
64	36	275
67	33	300
72	28	350
75	25	404
77	23	451
80	20	555

Figure 1: Proposed two layers of 5577 Å radiation.

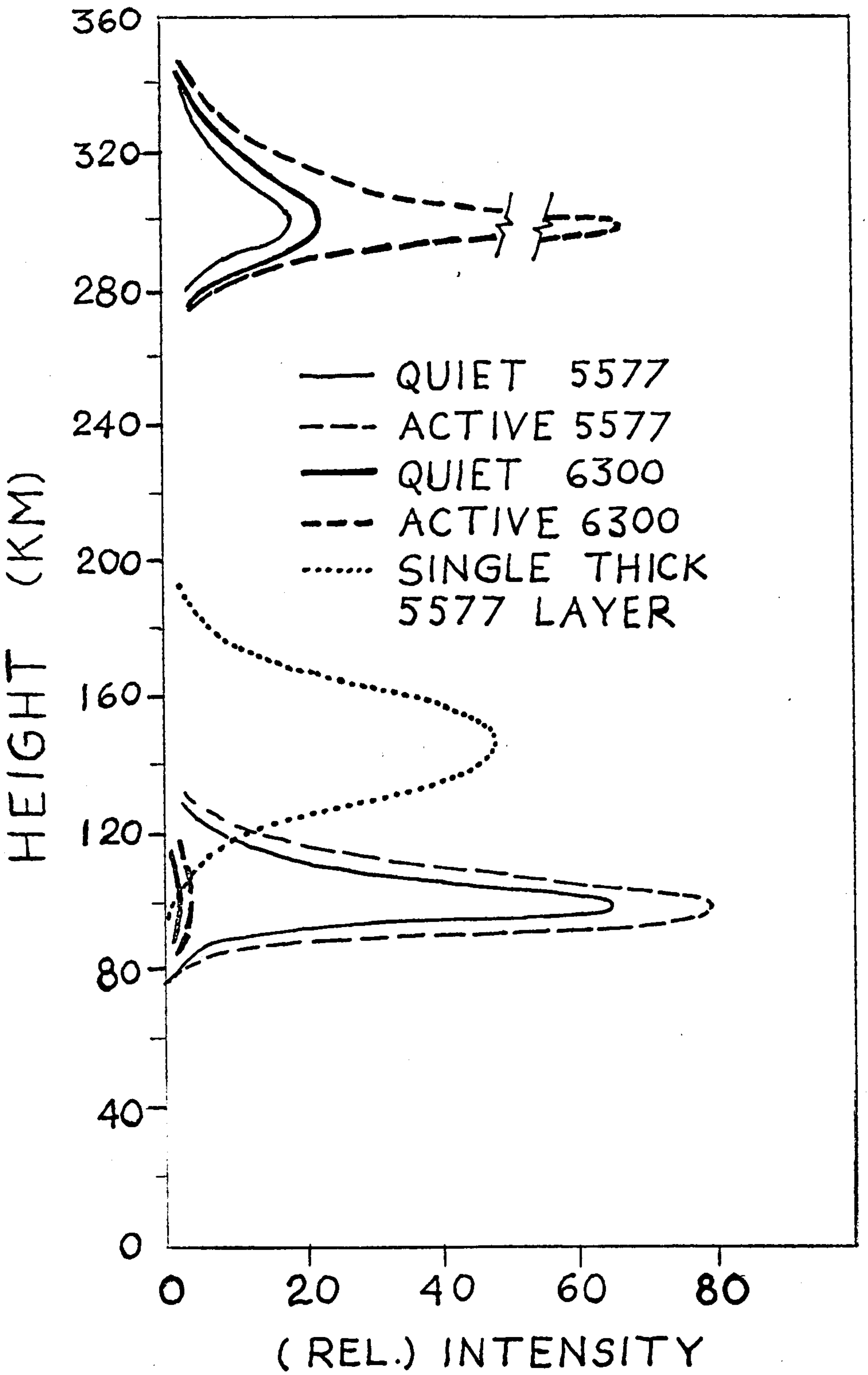

FIGURE 1